FREQUENCY TUNING OF AN e-BEAM PREIONIZED HIGH-PRESSURE CO_2 LASER

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Frequency tuning of the high-pressure CO_2 laser with an e-beam preionization is achieved for the first time. The laser frequency pulling effect of the multimode spectral structure on the CO_2 laser lines is observed in a Fabry Perot resonator with a diffraction grating. This effect reduces the cw tunability by a value of 0.5 cm^{-1} near the center of each laser line Frequency tuning without essential pulling is obtained by using the lens telescope expander. The laser linewidth in this case is less than 0.01 cm^{-1}. The absorption line of NH_3 is measured to demonstrate the possibilities of the laser as a ir high-resolution laser spectrometer.

In our previous paper [1] the possibility of tunable high-pressure ir molecular lasers was considered and the first experiments with the self-sustained μsec-duration pulsed discharge in a CO_2 + N_2 + He gas mixture at pressures up to 1.8 atm and in a SF_6 + H_2 + He mixture were carried out. In the present paper the frequency tunability of a CO_2 laser excited by an e-beam preionized non-selfsustained high-pressure discharge is investigated. The later method of spatially uniform excitation of high-pressure gas lasers was used for the first time in ref. [2].

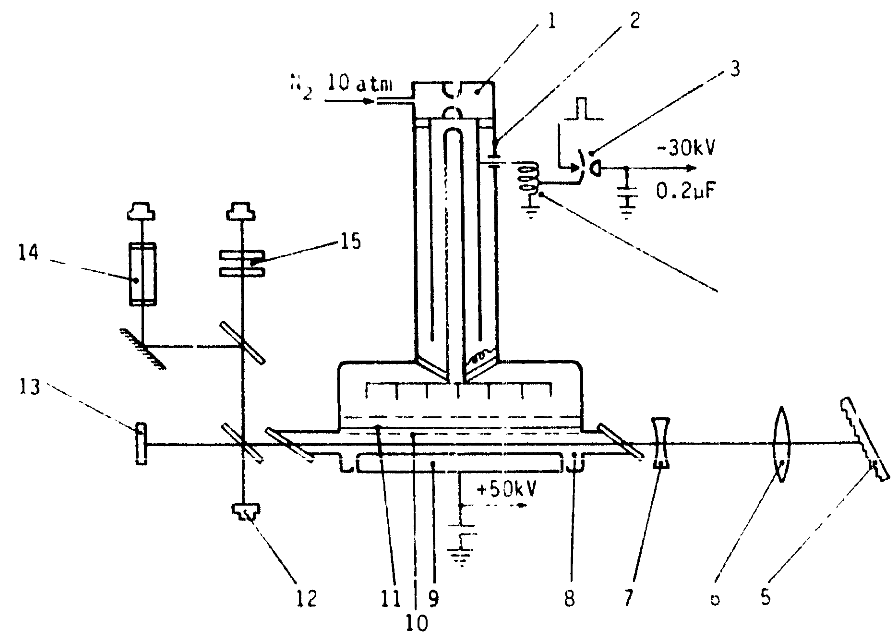

Fig. 1. Experimental set up. 1 High-pressure N_2 spark gap, 2 Coaxial Blumleine line; 3 Triggered air spark gap; 4. Pulse transformer 5. Grating; 6, 7 Telescope; 8 High-pressure volume; 9 Plane electrode, 10 Brass mesh, 11 Mylar film; 12. Thermopile. 13. Steel mirror, 14 NH_3 cell; 15. Fabry Perot interferometer

The coaxial Blumleine line electron gun with castor oil filling [3] was used for preionization of the high-pressure gas mixtures (fig. 1). The 350 kV, 12 nsec voltage pulse formed by the coaxial line was applied on the 1.5 cm acceleration vacuum gap between the autoemission cathods and the grounded metal mesh. The accelerated electrons run through the 85 μm mylar film and brass mesh into the high-pressure laser volume. The non-selfsustained pulsed discharge was excited in a 0.8 cm gap between the brass mesh and the polished flat electrode by using the 0.1 μF, 30 nH capacitor charged to V = 0–50 kV. The e-beam current in the laser volume is 100–200 A.

The resonator was formed by the plane steel mirror and the 100 grooves/mm, 30° blaze angle grating with the 90% reflection in the first order at 10 μm, mounted in the auto-collimation scheme. The grating was turned around its vertical axis with an accuracy of 2 arc sec. The galilean telescope with an angular magnification of 3.4 ×, a relative aperture of 1:10 and with the varied distance between NaCl lenses was used. The laser radiation was brought out through the NaCl plate to the thermopile and the mechanically scanned Fabry–Perot interferometer [4]. The dispersion interval of the interferometer is variable from 0.05 cm^{-1} up to 10 cm^{-1}. The reflection of laser light inside of the resonator by the polished electrode was removed by the diaphragm. The laser damage of the grating and formation of the laser spark on its surface was completely protected by using the telescope.

To obtain maximum gain [5] a $N_2:CO_2$ gas mixture was used with proportions from 2:1 to 4:1 excited at the maximum voltage under the spark breakdown threshold V_{sp}. The addition of helium is not expedient because of the lower broadening constant of the CO_2 laser lines (0.06 $cm^{-1}\,atm^{-1}$ against 0.08 $cm^{-1}\,atm^{-1}$ for N_2 [6]) and also due to strong reducing of the spark breakdown threshold. The pumping energy of the active volume ($35 \times 0.8 \times 1.0\ cm^3$) at p = 4 atm and with $N_2:CO_2$ = 2:1 could reach 20 J (0.7 J/cm^3) and the corresponding maximum gain was $K = 3 \times 10^{-2}\ cm^{-1}$. The pulse repetition rate of the laser was 0.05–1 Hz. The amplitude instability of the laser pulse for optimal excitation conditions did not exceed 5%.

The rotation of the grating in the plane resonator without telescope courses tuning of the laser frequency in the narrow spectral region near the line center. The laser frequency does not change essentially until the turning angle corresponding to the middle point between lines is achieved. Then the laser frequency suddenly "jumps" to the central region of the neighbouring laser line (fig. 2a). The frequency pulling effect is particularly large at low gas pressures and for spherical mirrors. The fact that the laser action takes place at a grating position corresponding to the middle frequency between CO_2 lines (fig. 2b) is not connected directly with frequency tuning. This means that the laser output versus turning angle curve is not a characteristic tuning curve. The slope of the tuning curve $d\nu_{osc}/d\nu_0$ at the line center of the P and R branches are approximately equal, but the tuning range for the R-branch is lower. This fact is quite unexpected taking into account the smaller line separation for the R-branch (1.2 cm^{-1}) compared with 1.8 cm^{-1} for the P-branch and the 2 times larger gain in the gap between lines for R-branch

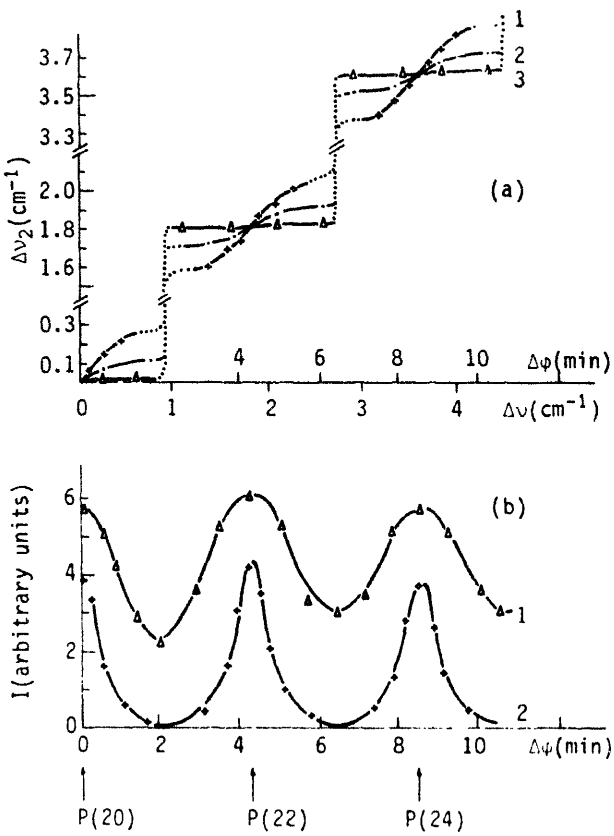

Fig. 2. Laser frequency (a) and energy output (b) versus the turning angle of grating and corresponding frequency of minimum selective loss $\Delta\nu_0$ at various pressures of the $N_2:CO_2$ 2:1 mixture (resonator without telescope).

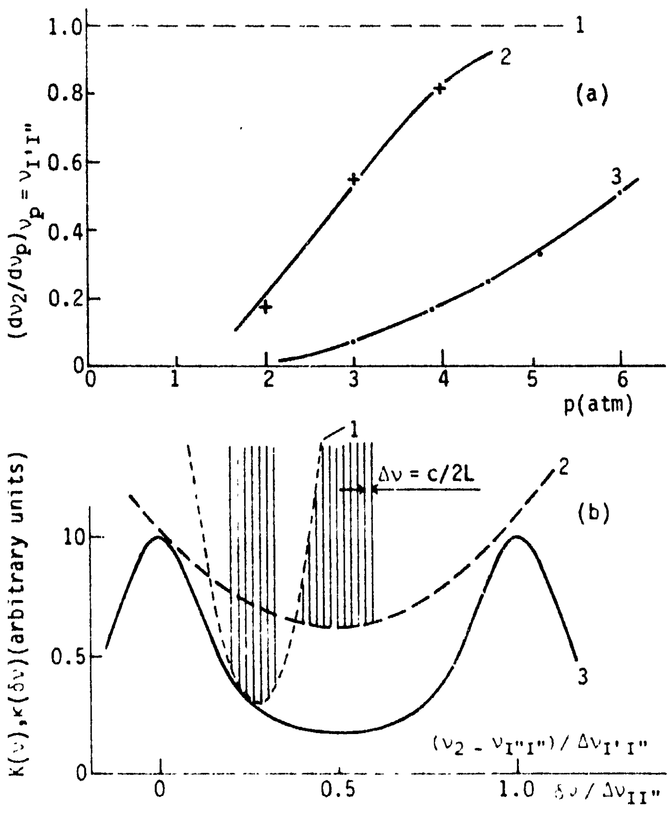

Fig. 3a). The slope of the tuning curve at the line center versus the gas pressure for resonator with (2) and without (3) telescope for P-branch. b) The influence of the loss function width on the frequency tuning.

at p = 4 atm. The latter two circumstances should provide better conditions for tuning on the R-branch.

The considerable pulling frequency effect is observed at pressures as high as 6 atm (fig. 3a, curve 3). The maximum achieved tuning range for system without telescope is 0.5 cm^{-1} near the center of CO_2 lines. The spectral width of the laser radiation is increasing with pressure achieving 0.1 cm^{-1} at 6 atm for relatively low pumping power. The slope of the tuning curve is considerably increased for the telescope with an optimal distance l_{opt} between the lenses (fig. 3a, curve 2). At $p \gtrsim 4$ atm the tuning takes place practically without frequency pulling. For $l > l_{opt}$ (positive equivalent lens) the value of $d\nu_{osc}/d\nu_0$ decreases, the threshold and losses are gradually increased and the laser alignment becomes more simple. For $l < l_{opt}$ (negative equivalent lens) $d\nu_{osc}/d\nu_0$ is the same as in the case of $l = l_{opt}$, but the losses and threshold are rapidly increased and the alignment region of the grating for the laser action is too narrow. The laser line width for the investigated pressures does not exceed 10^{-2} cm^{-1} (the frequency interval between longitudinal modes $c/2L$ = 0.005 cm^{-1}).

For quantitative purposes with regard to the tunability of high-pressure molecular lasers it is useful to introduce the function of the selective losses of the cavity $\kappa(\delta\nu)$, where $\delta\nu = \nu - \nu_0$, and ν_0 is the frequency of the selective losses minimum and width of the minimum is much more than $c/2L$. Laser action takes place at a single or several cavity frequencies in vicinity of the frequency, determined by the following conditions:

$$K(\nu) = \gamma + \kappa(\delta\nu), \tag{1}$$

$$dK(\nu)/d\nu = d\kappa(\delta\nu)/d\nu, \tag{2}$$

where $K(\nu)$ is the gain contour formed by overlapping molecular lines per unit length of cavity, γ denotes the nonselective losses per unit length. Conditions (1), (2) geometrically correspond to the contact of the gain contour and the selective loss curve at the laser frequency (fig. 3b). The selective loss function for resonator without telescope is rather wide and moving of the contact point by grating rotation is slow. For $|\nu_0 - \nu_{J'J''}| = \frac{1}{2}\Delta\nu_{J'J''}$ the selective loss curve touches at the same time two molecular lines and the frequency jump place. The observed relatively low tuning range on the R-branch lines can be explained from this point of view by the smaller penetration of the selective loss curve between more closely spaced gain lines of the R-branch. Consequently the displacement of the contact point relative to the line center is diminishing. For the resonator with the telescope the selective loss curve is considerably narrower and continuous tuning without essential frequency pulling becomes a reality even at relatively low pressure.

One of the most important laser parameters is the spectral width of the radiation. The main reason of the observed multimode laser action in the resonator without telescope at pressures higher than 2–3 atm is apparently the spatial modulation of the inversion population due to low molecular diffusion rates [7]. This effect is well known from solid-state laser physics. The molecular diffusion time between the nodes and the crest of the optical wave $\tau \approx \lambda^2/16D \approx 10^{-7}$ sec atm^{-1} is comparable with the laser pulse duration at $p \approx 1$ atm (the diffusion coefficient D = 0.5 atm cm^{2}sec^{-1}). The number of acting longitudinal laser modes is consider-

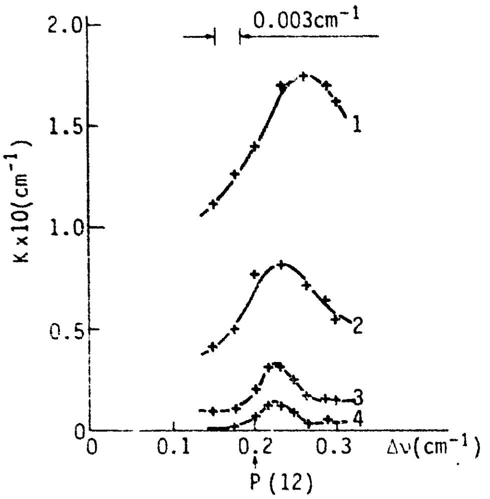

Fig. 4. NH_3 absorption line contour for various pressures of NH_3.

ably decreased in the resonator with the telescope due to the narrow curve of the selective losses. The observed narrowing of the laser radiation spectral width is the result.

The NH_3 absorption line at various pressures is shown in fig. 4 in order to illustrate the possibilities of the tunable CO_2 laser in high-resolution ir spectroscopy. The used laser has a 0.033 cm^{-1} radiation spectral width, a 0.2 cm^{-1} tuning range at 4.5 atm gas pressure. The maximum absorption coefficient of the NH_3 line does not change essentially in the investigated pressure diapason and is approximately 4×10^{-2} cm^{-1}. The absorption of the strong neighbouring NH_3 line and the spectral width of the laser radiation are taking into account. The broadening parameter has a value of 0.2 cm^{-1} atm^{-1}.

Hyperfine spectral structure investigations of the high-pressure CO_2 laser radiation are now in progress. The main question is: does a stable mode structure exist in such type of laser, and what are the main causes which define the minimum accessible laser linewidth.

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